

## SUPPLEMENTARY MATERIAL

**Table S1. Sources used to calculate carbon emission factors from charcoal and pole production.** The table presents direct and indirect activities related to each production and is subdivided by type of source (distance calculation, standard emissions, among others). Considering that sources were selected according to the type of information available for our research.

TYPE OF ACTIVITY	ACTIVITY		TYPE OF SOURCE	SOURCE
DIRECT	Tree cutting	Chainsaw	Brand models and Emission Factors	Husqvarna website [1]
	Boat driving	Log transport by small boat	Brand models	Yanmar website [2]
			Distance (charcoal factory – coupe)	Google Earth
	Fire monitoring	Kiln	Emission values	Lacaux <i>et al.</i> [3]
				Pennise <i>et al.</i> [4]
				Bailis <i>et al.</i> [5]
	Lorry driving	Charcoal transport by truck	Standard emissions	Gencat [6]
			Distance (charcoal factory – company – port terminal)	Distance calculator website [7]
	Exportation	Charcoal transport by Cargo ship	Container terminals location	SeaRates website [8]
			Standard emissions	OOCL website [9]
				Cefic [10]
			Distance	Sea Rates website [8]
				Sea- distance website [11]
INDIRECT	Boat driving	Tree cutters transport	Brand models	Yanmar website [2]
			Distance (charcoal factory – coupe)	Google Earth
	Moped	Workers and contractors transport	Standard emission	Gencat [6]
			Distance (registered residence – charcoal factory)	Distance calculator website [7]
	Car	Workers and contractors transport	Standard emissions	Gencat [6]
			Distance (registered residence – charcoal factory)	Distance calculator website [7]
	Charcoal burning	Barbecue	Emission values	Huang <i>et al.</i> [12]

**Table S2 Parameters taken into account to estimate carbon emission per contractor for each type of production.** (Arifin and Mustafa [13]).

TYPE OF CONTRACTOR	LICENSE (days)	WORKERS	ASSIGNED AREA (ha)	YIELD GREENWOOD (t.ha <sup>-1</sup> )
CHARCOAL	365	22.5	2.2	396
POLE	182.5	13.5	22.3	-

**Table S3 Emission factors for the Husqvarna chainsaws models.** All models are for professional use and sold in Japan. Adapted from. Husqvarna website [1]

EXHAUST EMISSIONS AVERAGE (g.kWh)								
MODEL	CILINDER (cm <sup>3</sup> )	CLASS	CO	C (CO)	HC	CO <sub>2</sub>	C (CO <sub>2</sub> )	TOTAL
576 XP	73.5	SH:3	313.00	134.33	65.50	853.00	232.43	366.76
560 XP	59.8	SH:3	241.00	103.43	56.00	802.00	218.53	321.96
550 XP	50.1	SH:3	271.00	116.31	57.00	837.00	228.07	344.37
395 XP	93.6	SH:3	390.50	167.60	125.00	731.50	199.32	366.92
<i>Mean</i>			303.88	130.41		805.88	219.58	350.00
<i>Median</i>			292.00	125.32		819.50	223.30	355.57

\* SH:3 Corresponds to level for non-road mobile exhaust emissions, with a larger displacement of 50 cc.

\* Values for carbon monoxide (CO) and carbon dioxide (CO<sub>2</sub>) were converted to Carbon values using 2.33 and 3.67 conversion factors, respectively.

\* As for hydrocarbons (HC) are showed as an average and not values are specified we did not take into account it.

**Table S4**      **Emission factors for the logging boats.** Adapted from: Yanmar official website [2].

BOAT TYPE	MODEL	RATED OUTPUT (mph)	RATED OUTPUT (kW)	(Km.kW- hr <sup>-1</sup> )	EXHAUST EMISSION (g/kWh)			
					min	max	mean	median
Sailboat + small craft	1GM10	9	6.6	2.19	0.98	1.29	1.16	1.18
Sailboat + small craft	2YM15	13.6	10	2.19	0.98	1.29	1.16	1.19
Sailboat + small craft	3YM20	21	15	2.25	0.95	1.26	1.13	1.15
Sailboat + small craft	3YM30AE	29.1	21.3	2.20	0.98	1.29	1.16	1.18
Sailboat + small craft	3JH5E	39	28.7	2.19	0.98	1.30	1.16	1.19
Sailboat + small craft	4JH45	45	33	2.19	0.98	1.29	1.16	1.18
Sailboat + small craft	4JH5E	54	40	2.17	0.99	1.30	1.17	1.20

Sailboat + small craft	4JH57	57	42	2.18	0.98	1.30	1.16	1.19
Sailboat + small craft	4JH4-TE	75	55.2	2.19	0.98	1.30	1.16	1.19
Sailboat + small craft	4JH80	80	59	2.18	0.98	1.30	1.17	1.19
Sailboat + small craft	4JH110	110	81	2.19	0.98	1.30	1.16	1.19
Sailboat + small craft	4JH4-HTE	110	81	2.19	0.98	1.30	1.16	1.19
Sailboat + small craft	4JH3-DTE	125	92	2.19	0.98	1.30	1.16	1.19
Powerboat engines	4LHA-HTTP	160	118	2.18	0.98	1.30	1.17	1.19
Powerboat engines	4LHA-DTP	200	147	2.19	0.98	1.29	1.16	1.19
Powerboat engines	ALHA-STP	240	177	2.18	0.98	1.30	1.17	1.19
Powerboat engines	6LPA-STP2	315	232	2.19	0.98	1.30	1.16	1.19
Powerboat engines	8LV-320	320	235	2.19	0.98	1.29	1.16	1.18
Powerboat engines	8LV-350	350	257	2.19	0.98	1.29	1.16	1.18
Powerboat engines	6LY2A-UTP	370	272	2.19	0.98	1.29	1.16	1.19
Powerboat engines	8LV-370	370	272	2.19	0.98	1.29	1.16	1.19
Powerboat engines	6LY3-UTP	380	279	2.19	0.98	1.29	1.16	1.18
Powerboat engines	6LY400	400	294	2.19	0.98	1.29	1.16	1.19
Powerboat engines	6LY2A-STP	440	324	2.19	0.98	1.30	1.16	1.19
Powerboat engines	6LY3-STP	440	324	2.19	0.98	1.30	1.16	1.19
Powerboat engines	6LY440	440	324		0.98	1.30	1.16	1.19
Powerboat engines	6LY3-ETP	480	353		0.98	1.29	1.16	1.19
<b>Mean</b>								1.16
<b>Median</b>								1.17

**Table S5 Distance (km) from the respective Charcoal Factory to the coupes available for Felling.**  
Adapted from Arifin and Mustafa [13].

RANGE	COMP. NUMBER	DISTANCE (km)	
		FINAL FELLING	INTERMEDIATE FELLING
KUALA SEPETANG (NORTH +SOUTH)	1	34.87	34.87
	2	25.72	25.72
	3	22.58	22.58
	4	27.63	27.63
	5	21.5	21.5
	6	16.9	16.9
	10	24.42	24.42
	14	9.56	9.56
	19	2.61	-
	20	5.23	-
	21	8.2	-
	22	10.72	10.72
	23	13.77	13.77
	24	15.33	15.33
	25	21.36	21.36

	27	6.92	-
	28	3.59	-
	30	2.37	2.37
	31	2.93	-
	32	5.67	-
	33	10.58	-
	36	12.37	12.37
	37	8.29	-
	38	7.79	7.79
	39	7.1	7.1
	41	10.67	-
	46	10.63	-
	47	-	-
	48	8.53	8.53
	49	6.25	6.25
<b>Mean</b>		12.02	11.46
<b>Median</b>		10.07	10.12
<b>KUALA TRONG</b>	51	10.13	10.13
	52	6.94	6.94
	53	8.37	8.37
	54	6.83	-
	55	3.13	3.13
	56	6.91	6.91
	57	8.87	8.87
	58	9.83	9.83
	59	11.68	-
	65	16.94	-
	66	18.61	-
	67	15.67	15.67
	68	15.67	15.67
	69	5.16	-
	70	16.1	-
	71	5.38	-
	72	6.13	6.13
	73	8.4	-
	74	13.52	-
	75	15.9	-
	76	13.24	-
	77	14.87	14.87
	78	15.78	-
	79	13.59	-
	82	10.54	-
	83	6.39	6.39
	84	13.35	-
	85	9.3	-
	86	8.84	8.84
<b>Mean</b>		10.73	10.97
<b>Median</b>		9.98	10.54
<b>SUNGAI KERANG</b>	89	9.49	9.49
	90	10.34	10.34
	92	5.95	5.95
	93	5.66	5.66
	94	9.16	9.16
	95	12.35	12.35
	98	9.52	-
	99	8.06	8.06
	100	4.22	-
	101	4.88	4.88
	102	3.1	3.1
	104	3.78	3.78
	105	6.37	6.37
	106	7.59	7.59
	107	9.13	9.13

	108	11.58	11.58
<b>Mean</b>		7.67	8.17
<b>Median</b>		8.06	8.44

\* Distance calculation using Google Earth's ♥ measure tool.

**Table S6 Emission factors, grams of pollutant per kilogram charcoal produced in kiln.** Adapted from: Lacaux *et al.* [3]; Pennise *et al.* [4].

EMISSION FACTORS, g OF POLLUTANT PER kg OF CHARCOAL PRODUCED											
SOURCE	CO <sub>2</sub>	C (CO <sub>2</sub> )	CO	C (CO)	CH <sub>4</sub>	CO <sub>2</sub> eq.	C (CH <sub>4</sub> )	N <sub>2</sub> O	CO <sub>2</sub> eq.	C (CO <sub>2</sub> )	TOTAL
Pennise <i>et al.</i> , 2001	1382	376.57	324	139.06	47.6	999.6	272.37	0.03	8.68	2.37	<b>842.24</b>
Lacaux <i>et al.</i> , 1994	-	420	-	100	-	-	30	-	-	5.91	<b>561.83</b>
<b>Mean</b>											<b>702.03</b>
<b>Median</b>											<b>702.03</b>

\* NO<sub>2</sub> values have been converted to CO<sub>2</sub> equivalents (conversion factor 310) and convert to Carbon values using 3.67 as conversion value (IPCC, 2007).

\* Only highlighted values were taken into account for our Carbon emission estimations.

**Table S7 Emission factors for heavy truck transport (g.km<sup>-1</sup>).** Adapted from: Gencat, 2017. [6]

				EMISSIONS g.km-h <sup>-1</sup>					
				21Km/h		69Km/h		102Km/h	
VEHICLE	FUEL	TYPE	WEIGHT(t)	CO <sub>2</sub>	C (CO <sub>2</sub> )	CO <sub>2</sub>	C (CO <sub>2</sub> )	CO <sub>2</sub>	C (CO <sub>2</sub> )
HEAVY	DIESEL	RIGID	<= 14	755.55	205.87	377.6	102.89	397.18	108.22
			> 14	156.72	425.54	458.7	124.99	452.12	123.19
		ARTICULATED	<= 34	1422.68	387.65	535.61	145.94	505.16	137.65
			> 34	2057.35	560.59	618.83	168.62	562.4	153.24
Mean				220.4					
Median				149.6					

\* Since velocity (km/h) values for truck transport are not specified in any source, this study will use average values to estimate a range of exhaust emissions.

**Table S8 Distance (km) from the charcoal factories to the Companies in charge of the charcoal exportation.** Adapted from: Distance Calculator [7].

CHARCOAL FACTORY	COMPANY LOCATION	DISTANCE (km)
KUALA SEPETANG	TAIPING	17
	KUALA KANGSAR	43
KUALA TRONG	TAIPING	20
	KUALA KANGSAR	38
SUNGAI KERANG	TAIPING	35

KUALA KANGSAR		* 52
Mean		34.17
Median		36.50

**Table S9 Distance (km) from the Companies to the Port terminals in Malaysia for charcoal exportation.** Adapted from: Distance Calculator [7].

COMPANY LOCATION	PORT TERMINAL	DISTANCE (km)
TAIPING	PORT KLANG	287
	PENANG	98
KUALA KANGSAR	PORT KLANG	261
	PENANG	127
Mean		193.25
Median		194.00

**Table S10 Distance (km) from the charcoal factories to the registered workers' residence.** Adapted from: Distance Calculator [7].

REGISTERED RESIDENCE	DISTANCE (km)		
	CHARCOAL FACTORIES		
	KUALA SEPETANG	KUALA TRONG	SUNGAI KERANG
Taiping, Perak	16	20	35
Matang, Perak	8	18	33
Changkat Jering, Perak	15	11	26
Kuala Kurau, Perak	50	62	77
Trong, Perak	21	-	16
Kuala Sepetang, Perak	-	24	38
Bukit Gantang, Perak	22	13	27
Semanggol, Perak	27	40	54
Kuala Kangsar, Perak	44	39	54
Sg. Kerang, Perak	38	15	-
Pantai Remis, Perak	54	32	18
Ayer Tawar, Perak	81	62	51
Mean			34.57
Median			32

**Table S11 Estimates of exhaust emission factors for cargo ships (g/ tonne-km).** Adapted from: Buhaug *et al.* [14]; Mc Kinnon and Piecyk [15].

TYPE		CAPACITY (t)	EMISSIONS g.tonne-km <sup>-1</sup>	
			CO <sub>2</sub>	C (CO <sub>2</sub> )
BULK SHIPS	Small tanker	844	20	5.45
	Large tanker	1 8371	5	1.36
	Deep-sea tanker	120 000	5	1.36
	Small bulk vessel	1 720	11	3.00
	Large bulk vessel	14 201	7	1.91
CONTAINER VESSEL	Small container vessel	2 500	13.5	3.68
	Larger container vessel	20 000	11.5	3.13
	Average deep sea container vessel*	-	8.4	2.29
GENERAL CARGO	10.000 +dwt	-	11.9	3.24
	5.000 - 9.999 dwt	-	15.8	4.31
	0-4.999 dwt	-	13.9	3.79
	10.000 +dwt, 100 +TEU	-	11	3.00
	5.000 - 9.999 dwt, 100 + TEU	-	17.5	4.77
	0-4.999 dwt, 100 +TEU	-	19.8	5.40
CONTAINER	8.000 + TEU	-	12.5	3.41
	5.000 - 7.999 TEU	-	16.6	4.52
	3.000 - 4.999 TEU	-	16.6	4.52
	2.000 - 2.999 TEU	-	20.0	5.45
	1.000 - 1.999 TEU	-	32.1	8.75

0- 999 TEU	-	36.3	9.89
Mean			4.16
Median			3.73

**Table S12 Distance from Malaysia port terminals (Port Klang and Penang) to Japanese terminals for charcoal exportation.** Adapted from: SeaRates [8].

CONTAINER TERMINAL		
MALAYSIA	JAPAN	DISTANCE (km)
Port Klang	Tokyo	5752.48
	Hakata	4970.41
	Tokuyama	5122.90
	Hiroshima	5122.90
	Mizushima	5311.54
	Kobe	5356.97
	Osaka	5372.70
	Yokkaichi	5372.70
	Nagoya	5534.50
	Shimizu	5613.73
	Yokohama	5732.92
	Kawasaki	5739.76
	Chiba	5754.29
	Niigata	5916.63
Penang	Tokyo	6037.84
	Hakata	5255.77
	Tokuyama	5408.26
	Hiroshima	5515.26
	Mizushima	5596.90
	Kobe	5642.33
	Osaka	5658.06
	Yokkaichi	5810.00
	Nagoya	5819.85
	Shimizu	5899.08
	Yokohama	6018.27
	Kawasaki	6025.11
	Chiba	6039.64
	Niigata	6201.99

<i>Mean</i>	5635.07
<i>Median</i>	5658.06

**Table S13 Car Standard Emissions (g/km).** Adapted from: Gencat [6]

FUEL	ENGINE SIZE (cc)	EMISSIONS g.km <sup>-1</sup>					
		21KM/H		69KM/H		102KM/H	
		CO <sub>2</sub>	C (CO <sub>2</sub> )	CO <sub>2</sub>	C (CO <sub>2</sub> )	CO <sub>2</sub>	C (CO <sub>2</sub> )
GASOLINE	< 0,8	158.18	43.10	108.74	29.63	129.33	35.24
	0.8 – 1.4	193.33	52.68	124.26	33.86	137.60	37.49
	1.4 – 2.0	232.85	63.45	145.96	39.77	154.68	42.15
	> 2.0	316.49	86.24	182.69	49.78	192.13	52.35
DIESEL	< 1.4	118	32.15	97.07	26.45	112.14	30.56
	1.4 – 2.0	203	55.31	129.32	35.24	145.39	39.62
	> 2.0	255.59	69.64	165.15	45.00	187.78	51.17
HYBRID	any	97.32	26.52	93.66	25.52	114.63	31.23
GLP	any	164.95	44.95	127.38	34.71	155.93	42.49
<i>Mean</i>							
<i>Median</i>							

\* Since velocity (km/h) values for truck transport are not specified in any source, this study will use average values to estimate a range of exhaust emissions.

**Table S14 Moped Standard Emissions (gC.km<sup>-1</sup>).** Adapted from: Gencat [6]

TYPE	CLASSIFICATION	EMISSIONS (g.km <sup>-1</sup> )	
		URBAN (25km/h)	
		CO <sub>2</sub>	C (CO <sub>2</sub> )
Moped	Conventional	73.45	20.01
	Median class Euro	58.76	16.01
<i>Mean</i>		18.01	
<i>Median</i>		18.01	

**Table S15 Distance in km from the charcoal factory to the places where pole are sold.** Adapted from: Distance Calculator [7].

Start Location	End Location	Distance (km)
KUALA SEPETANG	Kuala Lumpur	275
	Ipoh	73
	Taiping	17
	Selangor	277
	Jonor	75
	Kelantan	343
	Penang	100
KUALA TRONG (KAMPONG TERONG)	Kuala Lumpur	272
	Ipoh	70
	Taiping	22
	Selangor	274
	Honor	72
	Kelantan	339
	Penang	113
SUNGAI KERANG	Kuala Lumpur	278
	Ipoh	82
	Taiping	35
	Selangor	286
	Jonor	294
	Kelantan	352



	Penang	125
<b>Mean</b>		179.71
<b>Median</b>		125.00

**Table S16 Emission factors for light and heavy truck transport (gC.km<sup>-1</sup>) used for pole transport.** Adapted from: Gencat [6].

				EMISSIONS g/km					
				21K $\mu$ /H		69KM/H		102KM/H	
VEHICLE	FUEL	TYPE	WEIGHT (t)	CO2	C (CO2)	CO2	C (CO2)	CO2	C (CO2)
LIGHT	GASOLINA	-	-	316.77	86.31	175.71	47.88	171.12	46.63
	DIÈSEL	-	-	281.42	76.68	186.21	50.74	225.69	61.50
HEAVY	DIÈSEL	RÍGID	<= 14	755.55	205.87	377.6	102.89	397.18	108.22
			> 14	1 561.72	425.54	458.7	124.99	452.12	123.19
		ARTICULAT	<= 34	1 422.68	387.65	535.61	145.94	505.16	137.65
			> 34	2 057.35	560.59	618.83	168.62	562.4	153.24
Mean				167.45					
Median				124.09					

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